UNIVERSITI PUTRA MALAYSIA

EVALUATION OF NITRATE POLLUTION, HEALTH RISK AND GROUNDWATER VULNERABILITY IN AGRICULTURAL AND NON-AGRICULTURAL AREAS

AIDA SORAYA BINTI SHAMSUDDIN

FPSK(P) 2018 39

EVALUATION OF NITRATE POLLUTION, HEALTH RISK AND GROUNDWATER VULNERABILITY IN AGRICULTURAL AND NON-AGRICULTURAL AREAS

By

AIDA SORAYA BINTI SHAMSUDDIN

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirement for the Doctor of Philosophy

March 2018

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the Doctor of Philosophy

EVALUATION OF NITRATE POLLUTION, HEALTH RISK AND GROUNDWATER VULNERABILITY IN AGRICULTURAL AND NON-AGRICULTURAL AREAS

By

AIDA SORAYA BINTI SHAMSUDDIN

March 2018

Chair: Sharifah Norkhadijah Syed Ismail, PhD
Faculty: Medicine and Health Sciences

Majority population in Kelantan use shallow private well water for their domestic purposes. However, nitrate can easily contaminate the shallow wells. An agricultural activity has been identified as a major source of groundwater nitrate contamination. Meanwhile, discharge of septic tanks and livestock activities in non-agricultural area also contribute to nitrate contamination which consequently affects human health. Therefore, this study aimed to evaluate nitrate contamination, health risk and groundwater vulnerability in agricultural and non-agricultural areas. This cross-sectional study was conducted from October to December 2015 in Bachok district, Kelantan. Questionnaires were distributed among 300 respondents and their private well waters were analyzed for nitrate and others parameters such as pH, EC, NH_4^+, TDS, turbidity and salinity. Three substudies have been divided in this study; 1) Groundwater nitrate contamination assessment, 2) Health risk assessment of groundwater nitrate exposure and 3) Groundwater vulnerability assessment. In sub-study 1, nitrate concentrations were compared with the drinking water standard, potential nitrate sources were identified by multivariate analysis, groundwater quality was determined by different indices and distribution of nitrate were illustrated by spatial analysis. In sub-study 2, association of nitrate with perceived health symptoms and associated diseases were determined and health risks were calculated. In sub-study 3, the vulnerability of aquifer was evaluated by DRASTIC model. Based on measurement, nitrate in agricultural area (15.10 ± 15.90 mg/L NO_3-N) was significantly higher than non-agricultural area (5.81 ± 5.08 mg/L NO_3-N) ($Z = -5.83$, $p < 0.001$). About 46.0% and 24.0% samples in agricultural and non-agricultural areas, respectively, exceeded the drinking water quality standard. Principal component analysis (PCA) have identified the groundwater quality in the study area was influenced by natural processes and anthropogenic activities. Hierarchal cluster analysis (HCA) determined Cluster II in agricultural area was heavily contaminated by nitrate, while seawater intrusion was strongly influenced Cluster III in non-agricultural area. Groundwater Quality Index (GWQI) showed all the samples were suitable for drinking purpose. However, based on Nitrate Pollution Index (NPI), 80.7% and 56.0% of samples in agricultural and non-agricultural areas, respectively were polluted with nitrate. In sub-study 2, 21.29% and 18.75% of males and females in agricultural area, respectively had HQ > 1, and only 1.60% (n = 1) females in non-agricultural area had HQ > 1. In sub-study 3, DRASTIC index illustrated 27.14 % of areas fall under low vulnerable zones (159 – 175), 14.50% moderate vulnerable zones (176 – 192) and 58.36% high vulnerable zones (193 – 208). For the modified DRASTIC index, 8.47% of the area laid under low vulnerability (161 – 190), 61.03% moderate vulnerability (191 – 219) and 30.50% high vulnerability (220 – 248). The findings of this study are useful for developing protection alternatives of private well waters to prevent further deterioration of groundwater quality by nitrate and reduce the health risks for local residents. In addition, determination of vulnerable zones can be used to improve the sustainability of the groundwater resources through proper land use management.

Keywords: Groundwater; Nitrate; Health risk assessment; GIS; DRASTIC

Abstrak tesis yang dikemukan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Doktor Falsafah

PENILAIAN PENCEMARAN NITRAT, RISIKO KESIHATAN DAN KERENTANAN AIR BAWAH TANAH DI KAWASAN PERTANIAN DAN KAWASAN BUKAN PERTANIAN

Oleh

AIDA SORAYA BINTI SHAMSUDDIN

Mac 2018

Pengerusi: Sharifah Norkhadijah Syed Ismail, PhD
Fakulti: Perubatan dan Sains Kesihatan

Majoriti penduduk di Kelantan menggunakan air perigi persendirian yang cetek untuk kegunaan domestik mereka. Namun begitu, air perigi yang cetek boleh tercemar oleh nitrat. Aktiviti pertanian telah dikenalpasti sebagai sumber pencemaran utama air bawah tanah oleh nitrat. Sementara itu, pelepasan tangki septik dan aktiviti ternakan di kawasan bukan pertanian juga menyumbang kepada pencemaran nitrat yang seterusnya memberi kesan kepada kesihatan manusia. Oleh itu, objektif kajian ini adalah untuk menilai pencemaran nitrat, risiko kesihatan dan kerentanan air bawah tanah di kawasan pertanian dan kawasan bukan pertanian. Kajian keratan rentas ini telah dijalankan dari Oktober hingga Disember 2015 di daerah Bachok, Kelantan. Borang kaji selidik telah diedarkan di kalangan 300 responden dan sampel air perigi mereka dianalisis untuk nitrat dan parameter lain seperti pH, EC, NH_4^+, TDS, kekeruhan dan kemasinan. Tiga sub-kajian telah dibahagikan dalam kajian ini; 1) Penilaian pencemaran nitrat air bawah tanah, 2) Penilaian risiko kesihatan terhadap pendedahan nitrat air bawah tanah, dan 3) Penilaian kerentanan air bawah tanah. Dalam sub-kajian 1, kepekatan nitrat dibandingkan dengan piawaian kualiti air minum, potensi sumber nitrat dikenalpasti melalui analisis multivariat, kualiti air bawah tanah ditentukan oleh indek yang berbeza dan taburan nitrat digambarkan melalui analisis spasial. Dalam sub-kajian 2, perhubungan antara nitrat dengan gejala kesihatan dan penyakit berkait ditentukan dan risiko kesihatan juga dikira. Dalam sub-kajian 3, kerentanan air bawah tanah dinilai melalui model DRASTIC dan model DRASTIC yang diubahsuai. Berdasarkan keputusan, Dalam sub-kajian 1, nitrat di kawasan pertanian (15.10 ± 15.90 mg/L NO_3-N) jauh lebih tinggi daripada kawasan bukan pertanian (5.81 ± 5.08 mg/L NO_3-N) (Z = -5.83, $p < 0.001$). 46.0% dan 24.0% sampel di kawasan pertanian dan bukan pertanian, melebihi piawaian kualiti air minum. Analisis komponen utama (PCA) menunjukkan kualiti air tanah di kawasan kajian disebabkan oleh proses semulajadi dan aktiviti manusia. Analisis kelompok hierarki (HCA) menentukan Kelompok II di kawasan pertanian adalah yang sangat tercemar oleh nitrat, manakala pencerobohan air laut mempengaruhi Kelompok III di kawasan bukan pertanian. Indeks Kualiti Air Tanah (GWQI) menunjukkan kesemua sampel sesuai untuk diminum. Walau bagaimanapun, Indeks Pencemaran Nitrat (NPI) telah mengelaskan 80.7% sampel di kawasan pertanian dan 56.0% sampel di kawasan bukan pertanian telah tercemar dengan nitrat. Dalam sub-kajian 2, 21.29% lelaki dan 18.75% perempuan di kawasan pertanian mempunyai HQ > 1, dan hanya seorang perempuan di kawasan bukan pertanian mempunyai HQ > 1. Dalam sub-kajian 3, indeks DRASTIC menunjukkan 27.14% kawasan berada di zon kerentanan rendah (159 – 175), 14.50% di zon kerentanan sederhana (176 – 192) dan 58.36% di zon kerentanan tinggi (193 – 208). Untuk indeks DRASTIC yang diubahsuai, 8.47% kawasan berada di kerentanan rendah (161 – 190), 61.03% di zon kerentanan sederhana (191 – 219) dan 30.50% di zon kerentanan tinggi (220 – 248). Penemuan dalam kajian ini berguna untuk membangunkan perlindungan alternatif bagi air perigi persendirian untuk mengelakkan kemerosotan kualiti air bawah tanah oleh nitrat dan mengurangkan risiko kesihatan terhadap penduduk tempatan. Di samping itu, penentuan kerentanan zon boleh digunakan bagi meningkatkan kemampanan sumber air bawah tanah melalui pengurusan penggunaan tanah yang sesuai.

Kata kunci: Air bawah tanah; Nitrat; Penilaian risiko kesihatan; GIS; DRASTIC

ACKNOWLEDGEMENT

With sincere words of thanks to the Most Compassionate, the Most Gracious and the Most Merciful, ALLAH Who blessed me, helped me and gave me a light in the road of knowledge.

First of all, I would like to extend the deepest appreciation and gratitude to my supervisor, Dr. Sharifah Norkhadijah Syed Ismail for her professional insight, skilful guidance, encouraging attitude, and contribution of time and energy and advices throughout my study. I also would like to express my sincere appreciation to Assoc. Prof. Dr Emilia Zainal Abidin, Dr Ho Yu Bin and Assoc. Prof. Dr. Hafizan Juahir for their encouragement, time, advices and support.

I am indebted my deepest gratitude to all the government agencies staffs; Department of Mineral and Geosciences, Department of Drainage and Irrigation, Malaysian Centre for Geospatial Data Infrastructure, Bachok Land and District Office, Bachok District Council who have helped me with my maps and data collections. Special thanks to all my colleagues especially Nurul Hafiza Ab. Razak, Nurul Jannah Khairuddin, Fadhilah Othman, Nurul Ainni Abdul Latiff, Nurul Ain Mustafa Udin, Siti Zulaikha Rusmadi, Umi Raihanah, friends, staffs and students of Universiti Putra Malaysia for all kinds of support.

I also would love to great thanking for my father and mother, Tuan Haji Shamsuddin Derahman and Puan Hajah Samsiah Deraman and also my siblings (Shareen Adlina, Mohammad Sabri and Muhammad Fadhlullah) for their love, trust, care and support throughout my life. Last but not least, I wish to extend my deepest gratitude to my husband, Mohd Syarifuddin Su Reply for his constant patience, support and for standing with me during the period of my study. Thank you very much my dearest family.

I certify that a Thesis Examination Committee has met on 27 March 2018 to conduct the final examination of Aida Soraya binti Shamsuddin on her thesis entitled "Evaluation of Nitrate Pollution, Health Risk and Groundwater Vulnerability in Agricultural and Non-Agricultural Areas" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

Members of the Thesis Examination Committee were as follows:

Karmegam a/l Karuppiah, PhD
Senior Lecturer
Faculty of Medicine and Health Sciences
Universiti Putra Malaysia
(Chairman)

Abdul Rashid bin Mohamed Sharif, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Sarva Mangala Praveena, PhD
Associate Professor
Faculty of Medicine and Health Sciences
Universiti Putra Malaysia
(Internal Examiner)

Toru Watanabe, PhD
Professor
Yamagata University
Japan
(External Examiner)

NOR AINI AB. SHUKOR, PhD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 24 May 2018

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the Doctor of Philosophy. The members of the Supervisory Committee were as follows:

Sharifah NorKhadijah Syed Ismail, PhD
Senior Lecturer
Faculty of Medicine and Health Sciences
Universiti Putra Malaysia
(Chairman)

Emilia Zainal Abidin, PhD
Associate Professor
Faculty of Medicine and Helath Sciences
Universiti Putra Malaysia
(Member)

Ho Yu Bin, PhD
Senior Lecturer
Faculty of Medicine and Health Sciences
Universiti Putra Malaysia
(Member)

____
ROBIAH BINTI YUNUS, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

Declaration by graduate student

I hereby confirm that:

- this thesis is my original work;
- quotations, illustrations and citations have been duly referenced;
- this thesis has not been submitted previously or concurrently for any other degree at any other institutions;
- intellectual property from the thesis and copyright of thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (Research) Rules 2012;
- written permission must be obtained from supervisor and the office of Deputy Vice-Chancellor (Research and Innovation) before thesis is published (in theform of written, printed or in electronic form) including books, journals, modules, proceedings, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the Universiti Putra Malaysia (Research) Rules 2012;
- there is no plagiarism or data falsification/fabrication in the thesis, and scholarly integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the Universiti Putra Malaysia (Research) Rules 2012. The thesis has undergone plagiarism detection software.

Signature: ________________________ Date: ___________________

Name and Matric No.: Aida Soraya Binti Shamsuddin (GS 35342)

Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

Signature : ________________________________
Name of Chairman of Supervisory Committee : Dr. Sharifah Nor Khadijah Syed Ismail

Signature : ________________________________
Name of Member of Supervisory Committee : Associate Professor Dr. Emilia Zainal Abidin

Signature : ________________________________
Name of Member of Supervisory Committee : Dr. Ho Yu Bin

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AKSB	Air Kelantan Sdn Bhd
APHA	American Public Health Association
AT	Average Time
BDL	Below Detection Limit
BMI	Body Mass Index
BW	Body Weight
CDI	Chronic Daily Intake
CI	Confidence Interval
CV	Coefficient of Variance
Df	Degree of Freedom
DOE	Department of Environment
EC	Electrical Conductivity
ED	Exposure Duration
EF	Exposure Frequency
EU	European Union
GIS	Geographic Information System
GPS	Global Positioning System
GWQI	Groundwater Quality Index
HC	Health Canada
HCA	Hierarchical Cluster Analysis
HQ	Hazard Quotient
HR	Hazard Ratio
HRA	Health Risk Assessment
IDW	Inverse Distance Weighting
IR	Ingestion Rate
LOAEL	Lowest-Observed-Adverse-Effect-Level
LR	Logistic Regression
MCL	Maximum Contaminant Level
MDI	Modified DRASTIC Index
MetHb	Methemoglobin
MLD	Million Litre per Day
MOH	Ministry of Health
MRE	Mean Relative Error
NA	Not Available
NDWQS	Malaysian National Drinking Water Quality Standard
NH_4^+	Ammonium
NHMRC	Australian National and Medical Research Council
NO_2^-	Nitrite
NO_3^-	Nitrate
NO_3-N	Nitrate-Nitrogen
NOAEL	No-Observed-Adverse-Effect-Level
NPI	Nitrate Pollution Index
NZ	New Zealand
OR	Odd Ratio
PCA	Principal Component Analysis
Ref.	References
RfD	Reference Dose

RM	Ringgit Malaysia
RMSE	Root Mean Square Error
RR	Relative Risk
S.E	Standard Error
SD	Standard Deviation
Sig.	Significance
TDS	Total Dissolved Solids
UFs	Uncertainty Factors
USEPA	United States Environmental Protection Agency
WHO	World Health Organization

CHAPTER 1

INTRODUCTION

1.1 Background of Study

In Malaysia, less than 10% of the present water resources are developed from groundwater (Ahmed et al., 2014; Nazaruddin et al., 2017). The use of groundwater for domestic purposes is mainly confined to rural and remote areas, where there is no piped water supply (Nazaruddin et al., 2017). However, groundwater supplies > 70% of the public water supply in Kelantan state (Mohamed Zawawi et al., 2010; Nazaruddin et al., 2017). The groundwater demand increases significantly in Kelantan as they are facing with water problems of low quality surface water resources (Mohamed Zawawi et al., 2010; Jamaludin et al., 2013; Nazaruddin et al., 2017). Rural areas in Kelantan, such as Bachok district which become the present study area, use groundwater for their daily uses ranging from drinking, cooking, bathing, laundry to cleaning by obtaining it from shallow private wells as it is convenient to collect.

However, in recent years, groundwater is being subjected to an increasingly serious pollution. Contamination of groundwater by various pollutants released from different anthropogenic sources cause groundwater unsuitable for consumption and put human life as well as the whole environment at a greater risk (Khan et al., 2013). Nitrate is one of the most common and significant contaminants in groundwater around the world (Huang et al., 2011; Cheong et al., 2012; Czekaj et al., 2015; Rojas Fabro et al., 2015; Jang and Chen, 2015; Kazakis and Voudouris, 2015; Wheeler et al., 2015; Sadler et al., 2016). Septic systems, animal wastes and nitrogen fertilizers are the most common sources of high nitrate concentration in groundwater (Li et al., 2014; Sadler et al., 2016). Epidemiological investigations from previous studies have discovered the effects of nitrate on human body including as methemoglobinemia, multiple sclerosis, Non-Hodgkin lymphoma, diabetes and thyroid gland hypertrophy and gastric cancer (Masetti et al., 2008; Li et al., 2010; Huang et al., 2011; Jang and Chen, 2015; Rojas Fabro et al., 2015). Therefore, WHO (2011) and MOH (2009) have recommended 10 mg/L NO_3-N as the maximum contaminant level (MCL) for nitrate in drinking water. The discharge of groundwater nitrate to surface waters such as rivers and oceans also negatively affects aquatic plants and animals, with the development of anoxic zones and eutrophication (Masetti et al., 2008; Pastén-Zapata et al., 2014).

The occurrence and variability of nitrate concentrations in groundwater also a function of various interrelated and complex physical, chemical, and biological variables, such as the dominant land use categories, on-ground nitrogen loadings, groundwater recharge, soil characteristics, transport processes in unsaturated and saturated zones, and bacterial effects (Carbó et al., 2009; Wick et al., 2012; Alagha et al., 2014; Kazakis and Voudouris, 2015; Machiwal and Jha, 2015; Shrestha et al., 2016). The combination of these factors leads to high variability of nitrate concentration in groundwater. Due to the threat of elevated nitrate concentrations in groundwater, an assessment of the nitrate contamination based on its distribution and vulnerability of groundwater as well as its risk potential are essential. Hence, in this study, the contamination of nitrate in Bachok's groundwater was assessed by integrating monitoring, analytical, and modeling approaches.

1.2 Problem Statement

The demand for groundwater in Kelantan has increased tremendously. It becomes an important water source not only for public water supply, but also for domestic and agricultural purposes because of its widespread distribution, low development cost, and excellent quality (Mohamed Zawawi et al., 2010; Jamaludin et al., 2013; Chen et al., 2016). In 2010, approximately 163 Ml/day of groundwater are withdrawn for the whole Kelantan and expected to increase at a pace of 2.5% per year (Hussin et al., 2016). However, the local residents of north Kelantan, especially those living in villages such as in the Bachok district, normally get their water supply from their private well; dug well or borehole types (Mohd Kamal and Md. Hashim, 2014).

The private well water users tend to be exposed more frequently to higher levels of nitrate because they used it without any treatment and monitoring, shallower and closer to nitrate sources compared to public supply wells (Wheeler et al., 2015; Chen et al., 2016; Sadler et al., 2016; Shamsuddin et al., 2016). In addition, aquifer in the Bachok is covered by Quaternary alluvium, made up of gravel, sand, clay and silt, which is fragile and easily depleted due to over-exploitation of groundwater and anthropogenic activities at the surface (Hussin et al., 2016). Being shallow and relatively unprotected, the aquifer in this area is exposed to higher risk of nitrate contamination.

Land use of Bachok district which is covered primarily by the agricultural area also poses a significant potential of groundwater contamination by nitrate. Extensive research has indicated that agricultural activities may cause groundwater nitrate contamination and exceed the maximum acceptable level of nitrate for drinking water (10 mg/L NO_3-N) (Mohamed Zawawi et al., 2010; Ako et al., 2014; Narany et al., 2017). According to Nemčić-Jurec and Jazbec (2017), the agricultural activities contribute to an increased nitrate concentration in groundwater either directly by nitrate leaching from agrochemicals or by agrochemicals that affect the processes in the soil and increase nitrate leaching from the soil. Other than agricultural activities, the population growth in the Bachok district also increases the risk of nitrate contamination to the groundwater in the non-agricultural area. Dense populations and discharges from point sources like septic systems or broken sewer systems contribute significantly to groundwater contamination by nitrate (Nemčić-Jurec and Jazbec, 2017).

Many of the previous studies in Kelantan lack information on nitrate contamination and its effects on the groundwater quality within different land use types (agricultural and non-agricultural areas). The most common studies done previously were comparing the levels of nitrate in groundwater with the National drinking water quality standard (NDWQS) and this is insufficient to highlight the overall nitrate contamination (Jamaludin et al., 2013, Ahmad Roslan et al., 2014). Futhermore, limited studies found integrating the multivariate statistical techniques, human health risk assessment (HRA) and GIS-based geostatistical modeling to give a better understanding about nitrate contamination, its adverse effects on human health and the susceptibility of the aquifer to nitrate contamination. This research fills in the knowledge gap and provides an essential detailed assessment of the nitrate contamination in this area by combining those approaches.

1.3 Research Questions

This study is classified into three substudies; Sub-study 1) groundwater nitrate contamination assessment, Sub-study 2) health risk assessment of groundwater nitrate exposure, and Sub-study 3) groundwater vulnerability assessment. First sub-study examining the nitrate pollution in study area between the agricultural area and non-agricultural area. Second sub-study focusing on potential nitrate health risk to respondents in the study areas. Meanwhile, third sub-study focusing on groundwater vulnerability assessment. The research questions for each sub-study are listed below;

1.3.1 Sub-study 1: Groundwater Nitrate Contamination Assessment

1. What are the levels of nitrate in groundwater in the agricultural and non-agricultural areas and does it exceed the maximum contaminant level (MCL) of nitrate in the drinking water quality standard?
2. What are the factors affecting groundwater nitrate concentrations in the agricultural and non-agricultural areas?
3. What is the quality of groundwater and is it suitable for drinking purposes?
4. How is the distribution pattern of nitrate and groundwater quality in the agricultural and non-agricultural areas?

1.3.2 Sub-study 2: Health Risk Assessment of Groundwater Nitrate Exposure

5. Is there any association between nitrate concentrations with perceived health symptoms and associated diseases?
6. What are the chronic daily intake (CDI) and hazard quotient (HQ) values of nitrate per adult person in the study area and is it different between different areas and gender?
7. What is the spatial distribution pattern of nitrate health risk in the study area?

1.3.3 Sub-study 3: Groundwater Vulnerability Assessment

8. What is the degree of vulnerability of the groundwater to contamination in the study area?
9. How reliable is the vulnerability result in the conventional DRASTIC and modified DRASTIC and which of these models are suitable to represent the groundwater vulnerability in the study area?

1.4 Research Aims and Objectives

The general objective of this study is to evaluate nitrate contamination, health risk and groundwater vulnerability in the agricultural and non-agricultural areas in Bachok district. The specific objectives for each sub-study were listed below;

1.4.1 Sub-study 1: Groundwater Nitrate Contamination Assessment

1. To determine and compare the levels of nitrate in groundwater between agricultural and non-agricultural areas and with the drinking water quality standards.
2. To determine the relationship between physicochemical properties and nitrate concentrations in groundwater in the agricultural and non-agricultural areas
3. To identify the quality of groundwater and its suitability as drinking purposes in the agricultural and non-agricultural areas
4. To ascertain the spatial distribution pattern of nitrate pollution in the agricultural and non-agricultural areas

1.4.2 Sub-study 2: Health Risk Assessment of Groundwater Nitrate Exposure

5. To determine perceived health symptoms and diseases of the respodents in the agricultural and non-agricultural areas and its association with nitrate concentration
6. To determine and compare the chronic daily intake (CDI) and hazard quotient (HQ) value from the exposure to nitrate in groundwater and compare between different areas and gender
7. To assess the spatial distribution pattern of nitrate potential health risk in the agricultural and non-agricultural areas

1.4.3 Sub-study 3: Groundwater Vulnerability Assessment

8. To assess the degree of groundwater vulnerability to contamination in the study area
9. To compare the reliability between DRASTIC model and modified DRASTIC model and to select which of the models suitable to represent the study area

1.5 Research Hypotheses

The hypotheses of this study are listed below;

Sub-study 1: Groundwater Nitrate Contamination Assessment

1. There are significant differences of the nitrate concentration between agricultural area and non-agricultural area and to the drinking water quality standards.
2. There are significant relationships between physicochemical properties and the nitrate concentrations in the agricultural and non-agricultural areas.

Sub-study 2: Health Risk Assessment of Groundwater Nitrate Exposure

3. There are significant relationships between nitrate concentrations and health effects (perceived health symptoms and associated diseases) among the respondents.
4. There are significant differences in health risks of nitrate exposure between different areas and gender of respondents.

Sub-study 3: Groundwater Vulnerability Assessment

5. There are significant differences in groundwater vulnerability index values between DRASTIC Index (DI) and Modified DRASTIC Index (MDI).

1.6 Novelty

The novelty of this study comes from the assessment approach used in this study through an integrated multivariate statistical analysis with groundwater quality indices and health risk assessment. These approaches were integrated through GIS geospatial analysis to understand the pollution trend in the study area. In addition, the GIS-based DRASTIC model has been developed in this study to assess the vulnerability of groundwater to nitrate contamination and the reliability of these GIS vulnerability model has been tested. This study also illustrated the level of nitrate contamination comparatively between agricultural and non-agricultural areas in the high consumption of groundwater in Bachok, Kelantan. This study provided a better understanding of groundwater nitrate contamination in these areas as well as highlights the possible risk to the population through drinking water consumption. This was rarely being studied previously.

1.7 Conceptual Framework

Figure 1.1 illustrates the conceptual framework of this study. Bachok district was selected as the study area due to high consumption of groundwater. Two different areas were selected in this district; agricultural and non-agricultural areas. The agricultural activity such as nitrogen fertilizers application is the major source of groundwater nitrate contamination. Meanwhile, livestock activities, damaged and poorly maintained septic systems in the non-agricultural area also contribute to high levels of nitrate in groundwater (Carbó et al., 2009).

The private well water was selected for this study because it is used without any treatment and not routinely monitored. These reasons make private well waters exposed more frequently to nitrate contamination Ingestion of high nitrate may cause adverse effects on human health such as methemoglobinemia, gastric cancer, thyroid disease and diabetes (Liu et al., 2011; Wongsanit et al., 2015). Hence, the risks caused by ingestion of groundwater nitrate were estimated using health risk assessment (HRA). To better understanding about groundwater nitrate contamination, the vulnerability of groundwater was examined using the DRASTIC and modified DRASTIC model.

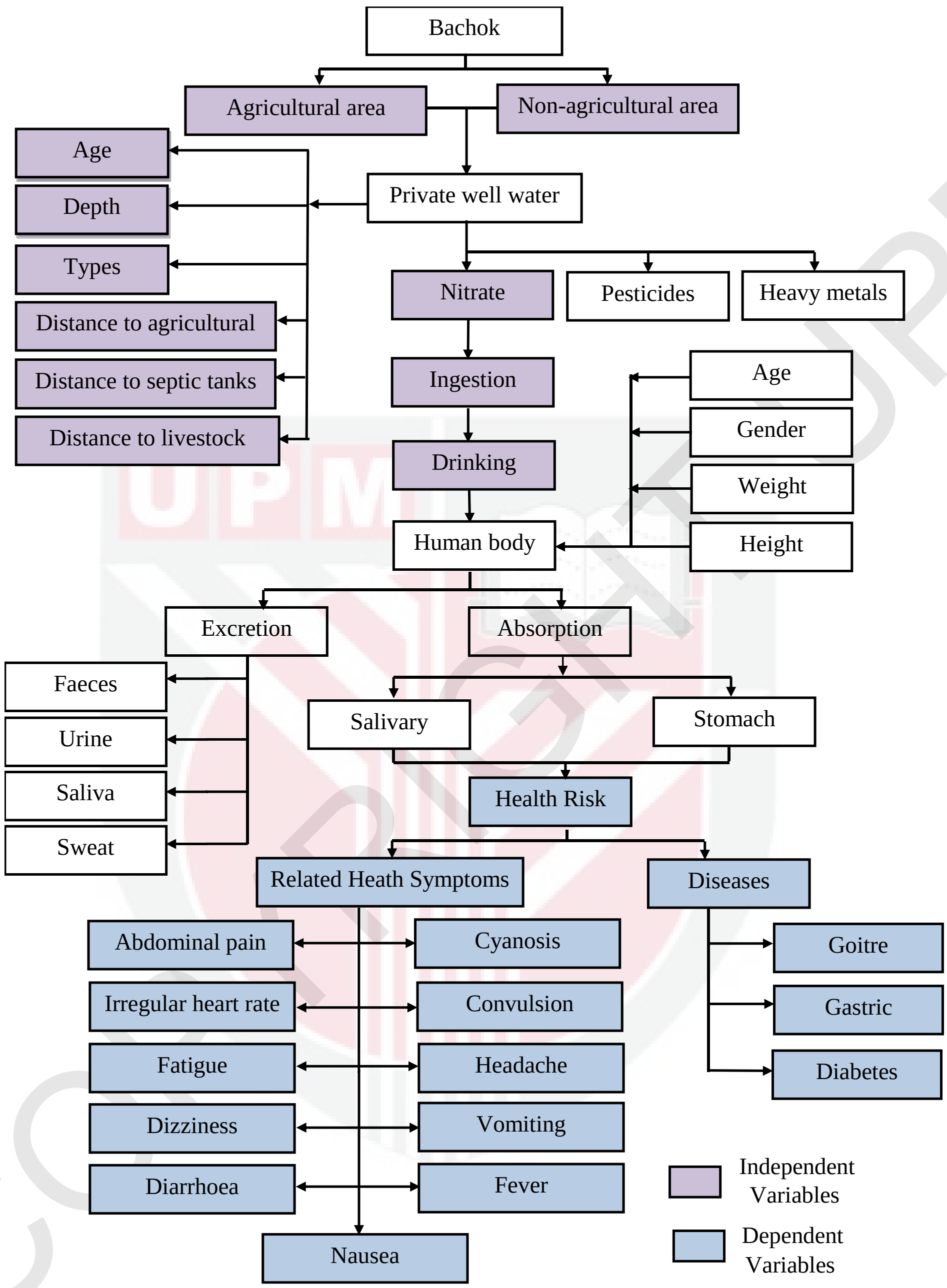

Figure 1.1: Conceptual framework

1.8 Significance of the Study

The sub-study 1 provides the information about levels and sources of nitrate in the private well waters in two different areas (agricultural and non-agricultural areas). Besides, this sub-study also provides the information on quality and suitability of groundwater for drinking water purposes. This information is useful for developing protection alternatives such as control of nitrogen fertilizers use and manure applications in the agricultural area. In addition, the private well water users also can protect their well by building a new well which uphill and far from nitrate sources such as livestock area, septic systems, barnyards and chemical storage facilities.

The sub-study 2 provides the knowledge to the respondents about the relationships of nitrate ingestion via drinking water and its adverse health effects. Besides, data gained from this study also useful for local authorities to develop adequate policies to protect private well water users from nitrate contamination. In addition, the data also may be useful for other research studies, especially in those exploring the relationships between nitrate exposure and adverse health outcomes.

The sub-study 3 provides aquifer vulnerability maps of the study area which identify areas with high pollution potential. The identification of the most vulnerable zones to contamination is important for local authorities to manage and monitor groundwater resources in these areas properly. Besides, this approach also reduces the cost of groundwater monitoring to define the geographic extent of contamination.

1.9 Thesis Outline

This thesis consists of six chapters which purposely to provide data on the nitrate contamination in groundwater as well as their potential health risk to human and groundwater vulnerability of Bachok district, Kelantan. Each chapter has been organized as follows:

Chapter 1 provides a brief introduction about the study's background, problem statement, research questions, objectives, research hypotheses, novelty and significance of the study. In Chapter 2, a comprehensive literature review is given. This chapter provides information such as groundwater occurrence, recharge and discharge and groundwater quality. The occurrence of nitrate, sources and factors affecting groundwater nitrate contamination, effects of nitrate on human health also are provided. The explanation about the methodology which applied in current research such as multivariate statistical analyses, groundwater quality index, health risk assessment model, and application of GIS also are provided.

Chapter 3 provides an assessment of groundwater nitrate concentrations in the agricultural and non-agricultural areas. The chapter starts with a brief introduction and research questions follow by methodology section. The description, sample size calculation, data collection and analysis can be found in the methodology section. The results begin with a description of well characteristics and physicochemical parameters of groundwater samples in the agricultural and non-agricultural areas. The subsequent section presents the levels of nitrate in the agricultural and non-agricultural areas and comparison with the National Drinking Water Quality Standard (NDWQS) (MOH, 2009) and WHO (2011). Determination of nitrate sources and groundwater quality using multivariate analysis and different indices also presented. The dispersion patterns of nitrate using GIS application also are provided in this chapter. In the final section, all the results are discussed and summarized.

Chapter 4 provides an assessment of health risk of groundwater nitrate exposure. The chapter begins with a brief introduction about nitrate ingestion and list of research questions. In the methodology section, data collection and analysis are provided. The calculation of potential risk using HQ also is provided. Then, the result section starts with the description of the socio-demographic background, follows by weight, height and BMI of respondents, the frequency of perceived health-related symptoms and associated diseases of nitrate exposure. The relationship between nitrate concentrations and perceived health symptoms and associated diseases also are presented in this chapter. The values of nitrate chronic daily intakes (CDI) and HQ of respondents for different areas (agricultural and non-agricultural areas) and gender (male and female) are provided. The findings are discussed and concluded in the last section.

Chapter 5 provides an assessment of groundwater vulnerability in the study area. This chapter begins with a brief introduction about groundwater vulnerability and lists of related research questions. The methodology section provides preparations of each map for the DRASTIC model, modified DRASTIC model and model validation. In the result section, maps of the DRASTIC index and modified DRASTIC index are provided. Then, the findings are discussed and concluded.

Chapter 6 provides the conclusions from each sub-study. This chapter also provides the limitation of this study and proposes several recommendations which may useful for the development of sustainable groundwater management and appropriate protection planning.

REFERENCES

Aĝca, N., Karanlik, S. and Ödemiş, B. (2014). Assessment of ammonium, nitrate, phosphate, and heavy metal pollution in groundwater from Amik Plain, southern Turkey. *Environmental Monitoring Assessment*, 186: 5921-5934. Doi 10.1007/s10661-014-3829-z.

Ahikary, P.P., Chandrasekharan, H., Chakraborty, D. and Kamble, K. (2010). Assessment of groundwater pollution in West Delhi, India using geostatistical approach. *Environmental Monitoring Assessment*, 167: 599-615.

Ahmad Roslan, A., Mohamad Sham, S., Syed Ismail, S.N. (2014). Nitrate levels in well water and population health risk of Kota Bharu and Bachok, Kelantan in different planting phases. *Advances in Environmental Biology*, 8 (15): 7-12.

Ahmed, F., Siwar, C. and Begum, R.A. (2014). Water resources in Malaysia: issues and challenges. *Journal of Food, Agriculture & Environment*, 12 (2): 1100-1104.

Aida Soraya, S., Sharifah Norkhadijah, S.I., Emilia, Z.A., Ho, Y.B. and Hafizan, J. (2016). Exposure to groundwater nitrate in intensive agriculture area, Kelantan, Malaysia. *Indian Journal Environmental Protection*, 36 (10): 808-817.

Ako, A.A., Eyong, G.E.T., Shimada, J., Koike, K., Hosono, T., Ichiyanagi, K., Richard, A., Tandia, B.K., Nkeng, G.E. and Roger, N.N. (2014). Nitrate contamination of groundwater in two areas of the Cameroon Volcanic Line (Banana Plain and Mount Cameroon area). *Applied Water Science*, 4: 99-113.

Aksever, F., Davraz, A. and Karagüzel, R. (2015). Relations of hydrogeologic factors and temporal variations of nitrate contents in groundwater, Sandikh basin, Turkey. *Environmental Earth Sciences*, 73: 2179-2196.

Al Hallaq, A.H. and Abu Elaish. (2012). Assessment of aquifer vulnerability to contamination in Khanyounis Governorate, Gaza Strip – Palestine, using the DRASTIC model within GIS environment. *Arabian Journal of Geosciences*, 5: 833-847.

Alabdula'aly, A., Al-Rehaili, A.M., Al-Zarah, A.I. and Khan, M.A. (2010). Assessment of nitrate concentration in groundwater in Saudi Arabia. *Environmental Monitoring Assessment*, 161: 1-9.

Alagha, J.S., Md Said, M.A. and Mogheir, Y. (2014). Modeling of nitrate concentration in groundwater using artificial intelligence approach – a case study of Gaza coastal aquifer. *Environmental Monitoring Assessment*, 186: 35-45.

Almasri, M.N. and Kaluarachchi, J.J. (2007). Modeling nitrate contamination of groundwater in agricultural watersheds. *Journal of Hydrology*, 343: 211-229.

Almasri, M.N.and Kaluarachchi, J.J. (2004). Assessment and management of long-term nitrate pollution of groundwater in agriculture-dominated watershed. *Journal of Hydrology*, 294 (1-4): 225-245.

Al-Rawabdeh, A.M., Al-Ansari, N.A., Al-Taani, A.A. and Knutsson, S. (2013). A GIS-based Drastic model for assessing aquifer vulnerability in Amman-Zerqa groundwater basin, Jordan. *Engineering*, 5: 490-504.

Alwathaf, Y. and El Mansouri, B. (2011). Assessment of aquifer vulnerability based on GIS and ARCGIS methods: a case study of the Sana'a Basin (Yemen). *Journal of Water Resource and Protection*, 3: 845-855.

Amano, H., Nakagawa, K. and Berndtsson, R. (2016). Groundwater geochemistry of a nitrate-contaminated agricultural site. *Environmental Earth Sciences*, 75:1145.

Amin, M.M., Ebrahimi, A., Hajian, M., Iranpanah, N. and Bina, B. (2010). Spatial analysis of three agrichemicals in groundwater of Isfahan using GS^+. *Iranian Journal of Environmental Health Science and Engineering*, 7(1): 71-80.

Amiri, V., Rezaei, M. and Sohrabi, N. (2014). Groundwater quality assessment using entropy weighted water quality index (EWQI) in Lenjanat, Iran. *Environmental Earth Science*, 73: 3470-3490.

Andrade, A.I.A.S.S. and Stigter, T.Y. (2009). Multi-method assessment of nitrate and pesticide contamination in shallow alluvial groundwater as a function of hydrogeological setting and land use. *Agricultural Water Management*, 96: 1751-1765.

Annapoorani, A., Murugesan, A., Ramu, A. and Renganathan, N.G. (2014). Hydrochemistry of groundwater in and around Chennai, India – a case study. *Research Journal of Chemical Sciences*, 4 (4): 99-106.

APHA. (2005). *Standard methods for the examination of water and wastewate*r. 21st Edn. American Water Works Association, Water Environment Federation, Washington.

Arauzo, M. (2017). Vulnerability of groundwater resources to nitrate pollution: a simple and effective procedure for delimiting Nitrate Vulnerable Zones. *Science of the Total Environment*, 575: 799-812.

Armah, F.A., Odoi, J.O., Afrifa, E.K.A., Pappoe, A.N.M., Yawson, D.O. and Essandoh, P.K. (2011). Spatial variability of trace metals in surface and groundwater within a contaminated mining environment in Ghana. Research *Journal of Environmental and Earth Sciences*, 3(5): 546-554.

Aschebrook-Kilfoy, B., Heltshe, S.L., Nuckols, J.R., Sabra, M.M., Shuldiner, A.R., Mitchell, B.D., Airola, M., Holford, T.R., Zhang, Y. and Ward, M.H. (2012). Modeled nitrate levels in well water supplies prevalence of abnormal thyroid conditions among the Old Order Amish in Pennsylvania. *Environmental Health*, 11:6.

Avtar, R., Kumar, P., Surjan, A., Gupta, L.N. and Roychowdhury, K. (2013). Geochemical process regulating groundwater chemistry with special reference to nitrate and fluoride enrichment in Chhatarpur area, Madhya Pradesh, India. *Environmental Earth Sciences*, 70: 1699-1708.

Awawdeh, M., Obeidat, M. and Zaiter, G. (2014). Groundwater vulnerability assessment in the vicinity of Ramtha wastewater treatment plant, North Jordan. *Applied Water Sciences*, Doi: 10.1007/s13201-014-0194-6.

Azizullah, A., Khattak, M.N.K., Richter, P. and Häder, D-P. (2011). Water pollution in Pakistan and its impact on public health – A review. *Environment International*, 37: 479-497.

Baalousha, H.M (2016). Groundwater vulnerability mapping of Qatar aquifers..*Journal of African Earth Sciences*, 124: 75-93.

Babiker, I.S., Mohamed, M.A.A. and Hiyama, T. (2007). Assessing groundwater quality using GIS. *Water Resource Management*, 21: 699-715.

Babiker, I.S., Mohamed, M.A.A., Hiyama, T. and Kato, K. (2005). A GIS-based DRASTIC model for assessing aquifer vulnerability in Kakamigahara Heights, Gifu Prefecture, central Japan. *Science of the Total Environment*, 345: 127-140.

Babiker, I.S., Mohamed, M.A.A., Terao, H., Kato, K. and Ohta, K. (2004). Assessment of groundwatercontamination by nitrate leaching from intensive vegetable cultivation using geographical informationsystem. *Environmental International*, 29: 1009-1017.

Baghapour, M.A., Talebbeydokhti, N., Tabatabaee, S.H. and Nobandegani, A.F. (2014). Assessment of groundwater nitrate pollution and determination of groundwater protection zones using DRASTIC and Composite DRASTIC (CD) models: the case of Shiraz unconfined aquifer. *Journal of Health Sciences and Surveillance System*, 2 (2): 54-65.

Baily, A., Rock, L., Watson, C.J. and Fenton, O. (2011). Spatial and temporal variations in groundwater nitrate at an intensive dairy farm in south-east Ireland: Insights from stable isotope data. *Agriculture, Eco-systems and Environments*, 144 (1): 308-318.

Balathandayuthan, K., Mayilswami, C. and Tamilmani, D. (2015). Assessment of groundwater quality using GIS: a case study of Walayar watershed, Parambikulam-Aliyar-Palar Basin, Tamilnadu, India. C*urrent World Environment*, 10 (2): 602-609.

Barroso, M.F., Ramalhosa, M.J., Olhero, A., Antão, M.C., Pina, M.F., Guimarães, L., Teixeira, J., Afonso, M.J., Delerue-Matos, C. and Chaminé, H.I. (2015). Assessment of groundwater contamination in an agricultural peri-urban area (NW Portugal): an integrated approach. *Environmental Earth Sciences*, 73: 2881-2894.

Bartzas, G., Tinivella, F., Medini, L., Zaharaki, D. and Komnitsas, K. (2015). Assessment of groundwater contamination risk in an agricultural area in north Italy. *Information Processing in Agriculture*, 2: 109-120.

Benjamin Zhan, F., Brender, J.D., Han, Y., Suarez, L. and Langlois, P.H. (2006). GIS-EpiLink: a spatial search tool for linking environmental and health data. *Journals of Medical Systems*, 30: 405-412.

Bodrud-Doza, M., Towfiqul Islam, A.R.M., Ahmed, F., Das, S., Saha, N. and Rahman, M.S. (2016). Characterization of groundwater quality using water evaluation indices, multivariate statistics and geostatistics in central Bangladesh. *Water Science*, 30: 19-40.

Brender, J.D., Olive, J.M., Felkner, M., Suarez, L., Marckwardt, W. and Hendricks, K.A. (2004). Dietary nitrites and nitrates, nitrosable drugs, and neural tube defects. *Epidemiology*, 15(3): 330-336.

Brindha, K and Elango, L. (2014). Soil and groundwater quality with reference to nitrate in a semiarid agricultural region. *Arabian Journal of Geosciences*, 7: 4683-4695.

Brindha, K. and Elango, L. (2015). Cross comparison of five popular groundwater pollution vulnerability index approaches. *Journal of Hydrology*, 524: 597-613.

Bryan, N.S and van Grinsven, H. (2013). The role of nitrate in human health. *Advances in Agronomy*, 119: 153-182.

Camargo, J.A. and Alonso, Á. (2006). Ecological and toxicological effects of inorganic nitrogen pollution in aquatic ecosystems: a global assessment. *Environment International*, 32: 831-849.

Carbó, L.I., Flores, M.C. and Herrero, M.A. (2009). Well site conditions associated with nitrate contamination in a multilayer semiconfined aquifer of Buenos Aires, Argentina. *Environmental Geology*, 57: 1489 – 1500.

Cezar-Vaz, M.R., Bonow, C.A., Couto, A.M.d. and Gelati, T.R. (2015). Prevalance of digestive signs and symptoms and associated factors among rural worker. *Acta Paul Enferm*, 28 (5): 460-466.

Chandna, P., Khurana, M.L., Ladha, J.K., Punia, M., Mehla, R.S. and Gupta, R. (2011). Spatial and seasonal distribution of nitrate-N in groundwater beneath the rice-wheat cropping system of India: a geospatial analysis. *Environmental Monitoring Assessment*, 178: 545-562.

Chang, C-C., Chen, C-C., Wu, D-C., Yang, C-Y. (2010). Nitrates in drinking water and the risk of death from rectal cancer: does hardness in drinking water matter? *Journal of Toxicology and Environmental Health, Part A*, 73: 1337-1347.

Chen, J., Taniguchi, M., Liu, G., Miyaoka, K., Onodera, S., Tokunaga, T. and Fukushima, Y. (2007). Nitrate pollution of groundwater in the Yellow River delta, China. *Hydrogeology Journal*, 15 (8): 1605-1614.

Chen, J., Wu, H. and Qian, H. (2016). Groundwater nitrate contamination and associated health risk for the rural communities in an agricultural area of Ningxia, Northwest China. *Exposure and Health*, 8(3): 349-359.

Cheong, J-Y., Hamm, S-Y., Lee, J-H., Lee, K-S.and Woo, N-C. (2012). Groundwater nitrate contamination and risk assessment in an agricultural area, South Korea. *Environmental Earth Sciences*, 66: 1127-1136.

Chindo, I.Y., Karu, E., Ziyok, I. and Amanki, E.D. (2013). Physicochemical analysis of groundwater of selected areas of Dass and Ganjuwa local government areas, Bauchi state, Nigeria. *World Journal of Analytical Chemistry*, 1(4): 73-79.

Chiu, H.F., Tsai, S.S. and Yang, C.Y. (2007). Nitrate in drinking water and risk of death from bladder cancer: an ecological case-control study in Taiwan. *Journal of Toxicology and Environmental Health, Part A*, 70 (12): 1000-1004.

Croen, L.A., Todoroff, K. and Shaw, G.M. (2001). Maternal exposure to nitrate from drinking water and diet and risk for neural tube defects. *American Journal of Epidemiology*, 153: 325-331.

Cross, A., Cantor, K.P., Reif, J.S., Lynch, C.F. and Ward, M.H. (2004). Pancreatic cancer and drinking water and dietary sources of nitrate and nitrite. *American Journal of Epidemiology*, 159 (7): 693-701.

Czekaj, J., Jakóbczyk-Karpierz, S., Rubin, H., Sitek, S. and Witkowski, A.J. (2015). Identification of nitrate sources in groundwater and potential impact on drinking water reservoirs (Goczalkowice reservoir, Poland). *Physics and Chemistry of the Earth*, xxx: 1-12.

Da'as, A. and Walraevens, K. (2013). Hydrogeochemical investigation of groundwater in Jericho area in the Jordan Valley, West Bank, Palestine. *Journal of African Earth Sciences*, 82: 15-32.

Darwish, T., Atallah, T., Francis, R., Saab, C., Jomaa, I., Shaaban A., Sakka, H. and Zdrulli, P. (2011). Observations on soil and groundwater contamination with nitrate: A case study from Lebanon-East Mediterranean. *Agricultural Water Management*, 99(1): 74-84.

Dash, J.P., Sarangi, A. and Singh, D.K. (2010). Spatial variability of groundwater depth and quality parameters in the national capital Territory of Delhi. *Environmental Management*, 45: 640-650.

Dohare, D., Deshpande, S. and Kotiya, A. (2014). Analysis of groundwater quality parameters: a review. *Research Journal of Engineering Sciences*, 3 (5): 26-31.

Dong, Z., Liu, Y., Duan, L., Bekele, D. and Naidu, R. (2015). Uncertainties in human health risk assessment of environmental contaminants: a review and presepctive. *Environment International*, 85: 120-132.

Douagui, A.G., Kouame, I.K., Koffi, K., Goula, A.T.B., Dibi, B., Gone, D.L., Coulibaly, K., Seka, A.M., Kouassi, A.K., Mangoua, J.M.O. and Savane, I. (2012). Assessment of the bacteriological quality and nitrate pollution risk of Quaternary groundwater in the southern part of Abidjan District (Côte d'Ivore). *Journal of Hydro-environment Research*, 6: 227-238.

Du Prel, J-B., Hommel, G., Röhrig, B. and Blettener, M. (2009). Confidence interval or p-value? *Deutsches Ärzteblatt International*, 196 (19): 335-339.

El Alfy, M. (2012). Integrated geostatistics and GIS techniques for assessing groundwater contamination in Al Arish area, Sinai, Egypt. *Arabian Journal of Geosciences*, 5: 197-215.

El Alfy, M., Lashin, A., Al-Arifi, N. and Al-Bassam, A. (2015). Groundwater characteristics and pollution assessment using integrated hydrochemical investigations GIS and multivariate geostatistical techniques in arid areas. *Water Resources Management*, 29: 5593-5612.

Elisante, E., and Muzuka, A.N.N. (2017). Occurrence of nitrate in Tanzanian groundwater aquifers: A revew. *Applied Water Science*, 7: 71-87.

Espejo-Herrera, N., Cantor, K.P., Malats, N., Silverman, D.T., Tardón. A., García-Closas, R., Serra, C., Kogevinas, M. and Villanueva, C.M. (2015). Nitrate in drinking water and bladder cancer risk in Spain. *Environmental Research*, 137: 299-307.

Fujii, H., Nakagawa, K. and Kagabu, M. (2016). Decomposition approach of the nitrogen generation process: empirical study on the Shimabara Peninsula in Japan. *Environmental Science and Pollution Research*, Doi: 10.1007/s11356-016-7522-3.

Gao, Y., Yu, G., Luo, C. and Zhou, P. (2012). Groundwater nitrogen pollution and assessment of its health risks: a case study of a typical village in rural-urban continuum, China. *PloS ONE*, 7(4): e33982. Doi: 10.1371/journal.pone.0033982.

Gardner, K.K. and Vogel, R.M. (2005). Predicting groundwater nitrate concentration from land use. *Ground water*, 43 (3): 343-352.

Gasim, M.B., Azid, A., hairoma, N., Yaakub, N., Muhamad, H., Azaman, F., Abdul Wahab, N. (2017). Study on selected parameters of groundwater quality based on different tides, East Coast of Terengganu, Malaysia. *Asian Journal of Applied Sciences*, 10 (1): 18-24.

Gatseva, P.D. and Argirova, M.D. (2005). Iodine status of children living in areas with high nitrate levels in water. *Archives of Environmental & Occupational Health*, 6 (6): 317-319.

Gatseva, P.D. and Argirova, M.D. (2008). High-nitrate levels in drinking water may be a risk factor for dysfunction in children and pregnant women living in rural Bulgarian areas. *International Journal of Hygiene and Environmental Health*, 211: 555-559.

Gilbert, A. and Chakraborty, J. (2011). Using geographically weighted regression for environmental justice analysis: cumulative cancer risks from air toxics in Florida. *Social Science Research*. 40: 273-286.

Gilchrist, M., Winyard, P.G. and Benjamin, N. (2010). Review: dietary nitrate – good or bad? *Nitric Oxide*, 22 (2): 104-109.

Gong, G., Mattevada, S. and O'Bryant, S.E. (2014). Comparison of the accuracy of kriging and IDW interpolations in estimating groundwater arsenic concentrations in Texas. *Environmental Research*, 130: 59-69.

Griesenbeck, J.S., Brender, J.D., Sharkey, J.R., Steck, M.D., Huber, J.C., Rene, A.A., McDonald, T.J., Romitti, P.A., Canfield, M.A., Langlois, P.H. and Suarez, L. (2010). Maternal characteristics associated with the dietary intake of nitrates, nitrites and nitrosamines in women of child-bearing age: a cross-sectional study. *Environmental Health*, 9: 10.

Gupta, S.K., Gupta, R.C., Chhabra, S.K., Eskiocak, S., Gupta, A.B. and Gupta, R. (2008). Health issues related to N pollution in water and air. *Indian Agriculture, Environment and Health*, 94(11): 1469-1477.

Hamzah, Z., Wan Rosdi, W.N., Hj. Wook, A.K. and Saat, A. (2014). Determination of major ions concentrations in Kelantan well water using EDXRF and ion chromatography. *The Malaysian Journal of Analytical Sciences*, 18 (1): 178-184.

Hannas, B.R., Das, P.C., Li, H. and LeBlanc, G.A. (2010). Intracellular conversion of environmental nitrate and nitrite to nitric oxide with resulting developmental toxicity to the crustacean *Daphnia magna*. *PloS ONE*, 5(8): e12453.

Hartmann, D.L. (2016). *Global Physical Climatology*. Volume 103 (Internatioanl Geophysics Series). San Diego: Academic Press.

Hoseinzadeh, E., Wei, C., Chavoshi, E. and Amin, M. (2016). Groundwater quality and nitrate pollution modeling: an integrated study of contour mapping and geographic information system. *Desalination and Water Treatment*, 1-12. Doi: 10.1080/19443994.2016.1150886.

Hossain, M.A., Sujaul, I.M. and Nasly, M.A. (2013). Water quality index: an indicator of surface water pollution in eastern part of peninsular Malaysia. *Research Journal of Recent Sciences*, 2 (10): 10-17.

Hu, K., Huang, Y., Li, H., Li, B., Chen, D. and White, R.E. (2005).Spatial variability of shallow groundwater level, electrical conductivity and nitrate concentration, and risk assessment of nitrate contamination in North China Plain.*Environmental International*, 31: 896-903.

Huan, H., Wang, J. and Teng, Y. (2012). Assessment and validation of groundwater vulnerability to nitrate based on a modified DRASTIC model: a case study in Jilin City of northeast China. *Science of the Total Environment*, 440: 14-23.

Huang, J., Xu, J., Liu, X., Liu, J. and Wang, L. (2011). Spatial distribution pattern analysis of groundwater nitrate nitrogen pollution in Shandong intensive farming regions of China using neural network method. *Mathematical and Computer Modelling*, 54: 995-1004.

Huang, Y.F., Ang, S.Y., Lee, K.M. and Lee, T.S. (2015). Quality of Water Resources in Malaysia, Research and Practices in Water Quality, Dr. Teang Shui Lee (Ed.), InTech, DOI: 10.5772/58969. Available from: https://www.intechopen.com/books/research-and-practices-in-water-quality/quality-of-water-resources-in-malaysia

Hussain, H., Yusoff, M.K., Ramli, M.F., abd Latif, P., Juahir, H. and Mohammed Zawawi, M.A. (2013). Temporal patterns and source apportionment of nitrate-nitrogen leaching in a paddy field at Kelantan, Malaysia. Pakistan *Journal of Biological Sciences*, 16(22): 1524-1530.

Hussain, Y., Ullah, S.F., Hussain, M.B., Aslam, A.Q., Akhter, G., Martinez-Carvajal, H. and Cárdenas-Soto, M. (2017). Modelling the vulnerability of groundwater to contamination in an unconfined alluvial aquifer in Pakistan. *Environmental Earth Sciences*, 76: 84.

Hussin, N.H., Yusoff, I., Alias, Y., Mohamad, S., Rahim, N.Y., Ashraf, M.A. (2013). Ionic liquid as medium to remove iron and other metal ions: a case study of the North Kelantan aquifer, Malaysia. *Environmental Earth Sciences*, Doi: 10.1007/s12665-013-2615-5.

Hussin, N.H., Yusoff, I., Wan Muhd Tahir, W.Z., Mohamed, I., Ibrahim, A.I.N. and Rambli, A. (2016). Multivariate statistical analysis for identifying water quality and hydrogeochemical evolution of shallow groundwater in Quaeternary deposits in the Lower Kelantan River Basin, Malaysian Peninsula. *Environmental Earth Sciences*, 75:1081.

Hynds, P.D., Misstear, B.D. and Gill, L.W. (2013). Unregulated private wells in the Republic of Ireland: consumer awareness, source susceptibility and protective actions. *Journal of Environmental Management*, 127: 278-288.

Idrus, A.S., Fauziah, M.N., Hani, M.H., Wan Rohaila, W.A. and Wan Mansor, H. (2014). Status of groundwater contamination in rural area, Kelantan. *IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT),* 8 (1): 72-80.

Igboekwe, M.U., Akankpo, A.O. and Udoinyang, I.E. (2011). Hydrochemical evaluation of groundwater quality in Michael Okpara University of Agriculture, Umudike and its Environs, southeastern Nigeria. *Journal of Water Resource and Protection*, 3: 925-929.

Inoue-Choi, M., Ward, M.H., Cerhan, J.R., Weyer, P.J., Anderson, K.E. and Robien, K. (2012). Interaction of nitrate folate on the risk of breast cancer among postmenopausal women. *Nutrition and Cancer*, 64 (5): 685-694.

Jalali, M. (2005). Nitrates leaching from agricultural land in Hamadan, western Iran. *Agriculture, Ecosystems & Environment*, 110 (3-4): 210-218.

Jamaludin, N., Mohd Sham, S. and Syed Ismail, S.N. (2013). Health risk assessment of nitrate exposure in well water of residents in intensive agriculture area. *American Journal of Applied Sciences*, 10 (5): 442-448.

Jang, C-S. and Chen, S-K. (2015). Integrating indicator-based geostatistical estimation and aquifer vulnerability of Nitrate-N for establishing groundwater protection zones. *Journal of Hydrology*, 523: 441-451.

Jasmin, I. and Mallikarjuna, P. (2014). Physicochemical quality evaluation of groundwater and development of drinking water quality index for Araniar River Basin, Tamil Nadu, India. *Environmental Monitoring Assessment*, 186: 935-948.

Javadi, S., Kavehkar, N., Mousavizadeh, M.H. and Mohammadi, K. (2011). Modification of DRASTIC model to map groundwater vulnerability to pollution using nitrate measurements in agricultural areas. *Journal of Agricultural Science and Technology*, 13: 239-249.

Jiang, Y, Guo, H., Jia, Y., Cao, Y. and Hu, C. (2015). Principal component analysis and hierarchical cluster analyses of arsenic groundwater geochemistry in the Hetao basin, Inner Mongolia, *Chemie der Erde*, 75: 197-205.

Jin, Z., Chen, Y., Wang, F. and Ogura, N. (2004). Detection of nitrate sources in urban groundwater by isotopic and chemical indicators, Hangzhou City, China. *Environmental Geology*, 45:1017-1024.

Kaliraj, S., Chandrasekar, N., Simon Peter, T., Selvakumar, S. and Magesh, N.S. (2015). Mapping of coastal aquifer vulnerable zone in the south west coast of Kanyakumari, South India, using GIS-based DRASTIC model. *Environmental Monitoring Assessment*, 187: 4073.

Karim, Z., Qureshi, B.A. and Ghouri, I. (2012). Spatial analysis of human health risk associated Trihalomethanes in drinking water: a case study of Karachi, Pakistan. *Journal of Chemistry*. Volume 2013, Article ID 805682, 7 pages. http://dx.doi.org/10.1155/2013/805682.

Kazakis, N. and Voudouris, K.S. (2015). Groundwater vulnerability and pollution assessment of porous aquifers to nitrate: Modifying the DRASTIC method using quantitative parameters. *Journal of Hydrology*, 525: 13-25.

Kelepertzis, E. (2014). Investigating the sources and potential health risks of environmental contaminants in the soils and drinking waters from the rural clusters in Thiva area (Greece).*Ecotoxicology and Environmental Safety*, 100: 258-265.

Khademikia, S., Rafiee, Z., Amin, M.M., Poursafa, P., Mansourian, M. and Modaberi, A. (2013). Association of nitrate, nitrite and total organic carbon (TOC) in drinking water and gastrointestinal disease. *Journal of Environmental and Public Health*, 2013: 1-4.

Khan, S., Shahnaz, M., Jehan, N., Rehman, S., Shah, M.T. and Din, I. (2013). Drinking water quality and human health risk in Charsadda district, Pakistan. *Journal of Cleaner Production*, 60: 93-101.

Kihumba, A.M., Longo, J.N. and Vanclooster, M. (2016). Modelling nitrate pollution pressure using multivariate statistical approach: the case of Kinshasa groundwater body, Democratic Republic of Congo. *Hydrogeology Journal*, 24: 425-437.

Kim, H., Kaown, D., Mayer, B., Lee, J-Y., Hyun, Y. and Lee, K-K. (2015). Identifying the sources of nitrate contamination of groundwater in an agricultural area (Haean basin, Korea) using isotope and microbial community analyses. *Science of the Total Environment*, 533: 566-572.

Kim, H-s.and Park, S-r. (2016). Hydrogeochemical characteristics of groundwater highly polluted with nitrate in an agricultural area of Hongseong, Korea. *Water*, 8 (345): 1-18. Doi: 10.3390/w8080345.

Kim, K-H., Yun, S-T., Kim, H-K.and Kim, J-W. (2015). Determination of natural backgrounds and thresholds of nitrate in South Korean groundwater using model-based statistical approaches. *Journal of Geochemical Exploration*, 148: 196-205.

Klein, B.E.K., McElroy, J.A., Klein, R., Howard, K.P. and Lee, K.E. (2013). Nitrate-nitrogen levels in rural drinking water: Is there an association with age-related macular degeneration? *Journal of Environmental Science and Health, Part A*, 48 (14): 1757-1763.

Kløve, B., Ala-Aho, P., Bertrand, G., Gurdak, J.J., Kupfersberger, H., Kværner, J., Muotka, T., Mykrä, H., Rossi, P., Uvo, C.B., Velasco, E., Pulido-Velazquez, M. (2013). Climate changes impacts on groundwater and dependent ecosystem. *Journal of Hydrology*, http://dx.doi.org/10.1016/j.jhydrol.2013.06.037

Kobayashi, J., Ohtake, K. and Uchida, H. (2015). No-rich diet for lifestyle-related diseases. *Nutrients*, 7: 4911-4937.

Krishna Kumar, S., Logeshkumaran, A., Magesh, N.S., Godson, P.S. and Chandrasekar, N. (2015). Hydro-geochemistry and application of water quality index (WQI) for groundwater quality assessment, Anna Nagar, part of Chennai City, Tamil Nadu, India. *Applied Water Sciences*, 5: 335-343.

Kuo, H.W., Wu, T.N. and Yang, C.Y. (2007). Nitrates in drinking water and risk of death from rectal cancer in Taiwan. *Journal of Toxicology and Environmental health, Part A*, 70 (20): 1717-1722.

Kura, N.U., Ramli, M.F., Sulaiman, W.N.A., Ibrahim, S., Aris, A.Z. and Mustapha, A. (2013). Evaluation of factors influencing the groundwater chemistry in a small tropical island of Malaysia. *International Journal of Environmental Research and Public Health*, 10: 1861-1881.

Lee, J-J., Jang, C-S., Wang, S-W.and Liu, C-W. (2007). Evaluation of potential health risk of arsenic-affected groundwater using indicator kriging and dose response model. *Science of the Total Environment*, 384: 151-162.

Li, J., Lu, W., Zeng, X., Yuan, J. and Yu, F. (2010). Analysis of spatial-temporal distributions of nitrate-N concentration in Shitoukoumen catchment in northeast China. *Environmental Monitoring Assessment*, 169: 335-345.

Li, J., Wang, Y., Xie, X. and Su, C. (2012). Hierarchical cluster analysis of arsenic and fluoride enrichments in groundwater from the Datong basin, Northern China. *Journal of Geochemical Exploration*, 118: 77-89.

Li, R., Merchant, J.W. and Chen, X-H.(2014). A geospatial approach for assessing groundwater vulnerability to nitrate contamination in agricultural settings. *Water, Air, & Soil Pollution*, 225: 2214.

Li, X., Li, J., Xi, B., Yuan, Z., Zhu, X., Zhang, X. (2015). Effects of groundwater level variations on the nitrate content of groundwater: a case study in Luoyang area, China. *Environmental Earth Sciences*, 74: 3969-3983.

Lin, C.Y., Abdullah, M.H., Musta, B., Aris, A.Z. and Praveena, S.M. (2010). Assessment of selected chemical and microbial parameters in groundwater of Pulau Tiga, Sabah, Malaysia. *Sains Malaysiana*, 39 (3): 337-345.

Liu, C-W., Lin, C-N., Jang, C-S., Ling, M-P.and Tsai, J-W. (2011). Assessing nitrate contamination and its potential health risk to Kinmen residents. *Environmental Geochemistry and Health*, 33: 503-514.

Liu, C-W., Wang, Y-B.and Jang, C-S. (2013). Probability-based nitrate contamination map of groundwater in Kinmen. *Environmental Monitoring Assessment*, 185: 10147-10156.

Machiwal, D. and Jha, M.K. (2015). Identifying sources of groundwater contamination in hard-rock aquifer system using multivariate statistical analyses and GIS-based geostatistical modeling techniques. *Journal of Hydrology: Regional Studies*, 4: 80-110.

Mahapatra, S.S., Sahu, M., Patel, R.K. and Panda, B.N. (2012). Prediction of water quality using principal component analysis. *Water Quality, Exposure and Health*, 4: 93-104.

Mahasim, N.W., Saat, A., Hamzah, Z., Sohari, R.R., Abdil Khali, K.H. *Nitrate and phosphate contents and quality of well water in north-eastern district of Kelantan*. Paper presented at the SKAM18, Johor Bharu. September 2005

Mair, A. and El-Kadi, A.I. (2013). Logistic regression modeling to assess groundwater vulnerability to contamination in Hawaii, USA. *Journal of Contaminant Hydrology*, 153: 1-23.

Manassaram, D.M., Backer, L.C. and Moll, D.M. (2006). A review of nitrates in drinking water: maternal exposure and adverse reproductive and developmental outcomes. *Environmental Health Perspectives*, 11 (4): 320-327.

Martínez, D., Moshione, E., Bocanegra, E., Galli, M.G. and Aravena, R. (2014). Distribution and origin of nitrate in groundwater in an urban and suburban aquifer in Mar del Plata, Argentina. *Environmental Earth Sciences*, 72: 1877-1886.

Masetti, M., Poli, S., Sterlacchini, S., Beretta, G.P. and Facchi, A. (2008). Spatial and statistical assessment of factors influencing nitrate contamination in groundwater. *Journal of Environmental Management*, 86: 272-281.

Mathialagan, K.R.P., Khan, M.M.A. and Mansor, H.E. (2017). Distribution pattern of nitrate and fluoride in shallow domestic groundwater wells in northern parts of Kelantan, Malaysia. *Science International (Lahore)*, 29 (1): 99-104.

Matiatos, I. (2016). Nitrate source identification in groundwater of multiple land-use areas by combining isotopes and multivariate statistical analysis: A case study of Asopos basin (Central Greece). *Science of the Total Environment*, 541: 802-814.

Menció, A., Mas-Pla, J., Otero, N., Regás, O., Boy-Roura, M., Puig, R., Bach, J., Domènech, C., Zamorano, M., Brusi, D. and Folch, A. (2016). Nitrate pollution of groundwater; all right…., but nothing else? *Science of the Total Environment*, 539: 241-251.

MOH (2009). *National Standard for Drinking Water Quality (NSDWQ)*. Engineering Services Division, Ministry of Health Malaysia, Kuala Lumpur, Malaysia.

Mohamed Zawawi, M.A., Yusoff, M.K., Hussain, H. and Nasir, S. (2010). Nitrate-Nitrogen concentration variation in groundwater flow in a paddy field. *Journal-The Institution of Engineers, Malaysia*, 71(4).

Mohammed, T.A. and Ghazali, A.H. (2009). Evaluation of yield and groundwater quality for selected wells in Malaysia. *Pertanika Journal of Science & Technology*, 17(1): 33-42.

Mohd Fuad, M.J., Junaidi, A.B., Habibah, A., Hamzah, J., Toriman, M.E., Lyndon, N., Selvadurai, A.C.Er.S.and Azima, A.M. (2012). The impact of pesticides on paddy farmers and ecosystem. *Advances in Natural and Applied Sciences*, 6 (1): 65-70.

Mohd Kamal, M.Z. and Md. Hasim, N. (2014). Comparison between groundwater qualities in Bachok with the National Drinking Water Quality Standard 1983. *International Journal of Technical Research and Applications*, 2 (7): 105-109.

Mohd Kamal, M.Z., Md. Hashim, M. and Mohd Zin, M.S. (2015). The effect of the ammonium concentration in the groundwater. *PEOPLE: International Journal of Social Sciences*, Special Issues: 313-319.

Mohebbi, M.R., Saeedi, R., Montazeri, A., Vaghefi, K.A., Labbafi, S., Oktaie, S., Abtahi, M. and Mohagheghian, A. (2013). Assessment of water quality in groundwater resources of Iran using a modified drinking water quality index (DWQI). *Ecological Indicators*, 30: 28-34.

Moratalla, Á, Gómez-Alday, J.J., Sanz, D., Castaño, S. and Heras, J.D.L. (2011). Evaluation of a GIS-based integrated vulnerability risk assessment for the Mancha Oriental System (SE Spain). *Water Resources Management*, 25: 3677-3697.

Mosaferi, M., Pourakbar, M., Shakerkhatibi, M., Fatehifar, E. and Belvasi, M. (2014). Quality modeling of drinking groundwater using GIS in rural communities, northwest of Iran. *Journal of Environmental Health and Engineering*, 12: 99

Murgulet, D. and Tick, G.R. (2009). Assessing the extent and sources of nitrate contamination in the aquifer system of southern Baldwin Country, Alabama. *Environmental Geology*, 58: 1051-1065.

Murgulet, D. and Tick, G.R. (2013). Understanding the sources and fate of nitrate in a highly developed aquifer system. *Journal of Contaminant Hydrology*, 155: 69-81.

Nabizadeh, R., Amin, M.V., Alimohammadi, M., Naddafi, K., Mahvi, A.H. and Yousefzadeh, S. (2013). Development of innovative computer software to facilitate the setup and computation of water quality index. *Journal of Environmental Health Science and Engineering*, 11:1.

Nagaraju, A., Sharifi, Z. and Balaji, E. (2016). Statistical and analytical evaluation of groundwater quality of Triputi area, Chittoor District, Andhra Pradesh, South India. *Journal of Geological Society of India*, 88: 222-234.

Nakagawa, K., Amano, H., Asakura, H., Berndtsson, R. (2016). Spatial trends of nitrate pollution and groundwater chemistry in Shimabara, Nagasaki, Japan. *Environmental Earth Sciences*, 75: 234.

Narany, T.S., Aris, A.Z., Sefie, A. and Keesstra, S. (2017). Detecting and predicting the impact of land use changes on groundwater quality, a case study in Northern Kelantan, Malaysia. *Science of the Total Environment*, 599-600: 844-853.

Nas, B. and Berktay, A. (2006). Groundwater contamination by nitrates in the city of Konya, (Turkey): A GIS perspective. *Journal of Environmental Management*. 79: 30-37.

Navoni, J.A., De Pietri, D., Olmos, V., Gimenez, C., Bovi Mitre, G., de Titto, G. and Villaamil Lepori, E.C. (2014). Human health risk assessment with spatial analysis: study of a population chronically exposed to arsenic through drinking water from Argentina. *Science of the Total Environment*, 499: 166-174.

Nazaruddin, D.A., Amiruzan, Z.S., Hussin, H. and Mohd Jafar, M.T. (2017). Integrated geological and multi-electrode resistivity surveys for groundwater investigation in Kampung Rahmat village and its vicinity, Jeli district, Kelantan, Malaysia. *Journal of Applied Geophysics*, 138: 23-32.

Nemčić-Jurec, J. and Jazbec, A. (2017). Point source pollution and variability of nitrate concentrations in water from shallow aquifers. *Applied Water Sciences*. 7: 1337-1348.

Neshat, A. and Pradhan, B. (2015). Risk assessment of groundwater pollution with a new methodological framework: application of Dempster-Shafer theory and GIS. *Natural Hazards*, 78: 1565-585.

Neshat, A., Pradhan, B., Pirasteh, S. and Mohd Shafri, H.Z. (2014). Estimating groundwater vulnerability to pollution using modified DRASTIC model in the Kerman agricultural area, Iran. *Environmental Earth Sciences*, 71: 3119-3131.

Ni, F-Q., Liu, G-D., Tan, Y-S.and Deng, Y. (2010). Spatial variation of health risk of groundwater for drinking water supply in Mingshan Country, Ya'an City, China. *Water Science and Engineering*, 3(4): 454-466.

Nosrati, K. and Van Den Eeckhaut, M. (2012). Assessment of groundwater quality using multivariate statistical techniques in Hashtgerd Plain, Iran. *Environmental Earth Sciences*, 65: 331-344.

Obeidat, M.M., Massadeh, A.M., Al-Ajlouni, A.M., Athamneh, F.S. (2007). Analysis and evaluation of nitrate levels in groundwater at Al-Hashimiya area, Jordan. *Environmental Monitoring Assessment*, 135: 475-486.

Obiefuna, G. and Orazulike, D.M. (2010). Physicochemical characteristics of groundwater quality from Yola area, northeastern Nigeria. *Journal of Applied Science and Environmental Management*, 14 (1): 5-11.

Ojo, O.I., Otieno, F.A.O., and Ochieng, G.M. 2012. Groundwater: characteristics, qualities, pollutions and treatments: an overview. *International Journal of Water Resources and Environmental Engineering*, 4 (6): 162-170.

Ouedraogo, I. Defourny, P. and Vanclooster, M. (2016). Mapping the groundwater vulnerability for pollution at the pan African scale. *Science of the Total Environment*, 544: 939-953.

Ozdemir, A. (2011). Using a binary logistic regression method and GIS for evaluating and mapping the groundwater spring potential in the Sultan Mountains (Aksehir, Turkey). *Journal of Hydrology*, 405: 123-136.

Pastén-Zapata, E., Ledesma_Ruiz, R., Harter, T., Ramírez, A.I. and Mahlknecht, J. (2014). Assessment of sources and fate of nitrate in shallow groundwater of an agricultural area by using a multi-tracer approach. *Science of the Total Environment*, 470-471: 855-864.

Pathak, D.R., Hiratsuka, A., Awata, I. and Chen, L. (2009). Groundwater vulnerability assessment in shallow aquifer of Kathmandu Valley using GIS-based DRASTIC model. *Environmental Geology*, 57: 1569-1578.

Pisciottta, A., Cusimano, G. and Favara, R. (2015). Groundwater nitrate risk assessment using intrinsic vulnerability methods: a comparative study of environmental impact by intensive farming in the Mediterranean region of Sicily, Italy. *Journal of Geochemical Exploration*, 156: 89-100.

Pour, A.B and Hashim, M. (2016). Application of PALSAR-2 remote sensing data for structural geology and topographic mapping in Kelantan river basin, Malaysia. *Earth and Environmental Science*, 37: 012067. Doi: 10.1088/1755-1315/37/1/012067.

Prasad, R.K., Sigh, V.S., Krishnamarcharyulu, S.K.G., Banerjee, P. (2011). Application of drastic model and GIS: for assessing vulnerability in hard rock granitic aquifer. *Environmental Monitoring Assessment*, 176: 143-155.

Putthividhya, A. and Pipitsombat, R. (2015). GIS-based and laboratory-scaled leaching assessment of agricultural contamination in heavily cultivated area of Thailand. *Environmental Earth Sciences*, 73: 3975-3986.

Qian, J., Wang, L., Liu, Y., Wu, B. and Wang, X. (2015). Distribution of nitrate and its implication for the contaminant source in groundwater of Huaibei Plain, Anhui Province. *Geosciences Journal*, 19 (3): 537-545.

Rahman, A. (2008). A GIS based DRASTIC model for assessing groundwater vulnerability in shallow aquifer in Aligarh, India. *Applied Geography*, 28: 32-53.

Rahmanian, N., Ali, S.H., Homayoonfard, M., Ali, N.J., Rehan, M., Sadef, Y. and Nizami, A.S. (2015). Analysis of physicochemical parameters to evaluate the drinking water quality in the State of Perak, Malaysia. *Journal of Chemistry*, Volume 2015: 1-10.

Rahmati, O., Samani, A.N., Mahmoodi, N. and Mahdavi, M. (2015). Assessment of the contribution of N-fertilizers to nitrate pollution of groundwater in western Iran (case study: Ghorveh-Dehgelan aquifer). *Water Quality, Exposure and Health*, 7:143-151.

Rajankar, P.N., Tambekar, D.H. and wate, S.R. (2011). Groundwater quality and water quality index at Bhandara District. *Environmental Monitoring Assessment*, 179: 619-625.

Rajasooriyar, L.D., Boelee, E., Prado, M.C.C.M. and Hiscock, K.M. (2013). Mapping the potential health implications of groundwater pollution in southern Sri Lanka. *Water Resources and Rural Development*, 1-2: 27-42.

Rajmohan, N. and Elango, L. (2005). Nutrient chemistry of groundwater in an intensively irrigated region of southern India. *Environmental Geology*, 47: 820-830.

Rao, N.S. (2006). Nitrate pollution and its distribution in the groundwater of Srikakulam district, Andhra Pradesh, India. *Environmental Geology*, 51: 631-645.

Rodriguez-Galiano, V., Mendes, M.P., Garcia-Soldado, M.J., Chica-Olmo, M., Ribeiro, L. (2014). Predictive modeling of groundwater nitrate pollution using Random Forest and multisource variables related to intrinsic and specific vulnerability: a case study in an agricultural setting (Southern Spain). *Science of the Total Environment*, 476-477: 189-206.

Rojas Fabro, A.Y., Ávila, J.G.P., Alberich, M.V.E., Sansores, S.A.C. and Camargo-Valero, M.A. (2015). Spatial distribution of nitrate health risk associated groundwater use as drinking water in Merida, Mexico. *Applied Geography*, 65: 49-57.

Ruckart, P.Z., Henderson, A.K., Black, M.L. and Flanders, W.D. (2008). Are nitrate levels in groundwater stable over time? *Journal of Exposure Science and Environmental Epidemiology*, 18: 129-133.

Sadat-Noori, S.M., Ebrahimi, K. and Liaghat, A.M. (2014). Groundwater quality assessment using the Water Quality Index and GIS in Saveh-Nobaran aquifer, Iran. *Environmental Earth Sciences*, 71: 3827-3843.

Sadeq, M., Moe, C.L., Attarassi, B., Cherkaoui, I., El Aouad, R. and Idrissi, L. (2008). Drinking water nitrate and prevalence of methemoglobinemia among infants and children aged 1 – 7 years in Moroccan areas. *International Journal of Hygiene and Environmental Health*, 211: 546-554.

Sadler, R., Maetam, B., Edokpolo, B., Connell, D., Yu, J., Stewart, D., Park, M-J., Gay, D. and Laksono, B. (2016). Health risk assessment for exposure to nitrate in drinking water from village wells in Semarang, Indonesia. *Environmental Pollution*, xxx : 1-8.

Saeedi, M., Abessi, O., Sharifi, F. and Meraji, H. (2010). Development of groundwater quality index. *Environmental Monitoring Assessment*, 163: 327-335.

Saghravani, S.R., Yusoff, I., Mustapha, S. and Saghravani, S.F. (2013). Estimating groundwater recharge using empirical method: a case study in the tropical zone. *Sains Malaysiana*, 42(5): 553-560.

Saghravani, S.R., Yusoff, I., Wan Md Tahir, W.Z. and Othman, Z. (2016). Estimating groundwater recharge based on mass balance evaluation of unsaturated zone in a coastal catchment characterized by tropical rainforest weather condition. *Environmental Earth Sciences,* 75: 668.

Saghravani, S.R., Yusoff, I., Wan Md Tahir, W.Z. and Othman, Z. (2015). Comparison of water table fluctuation and chloride mass balance methods for recharge estimation in a tropical rainforest climate: a case study from Kelantan River catchment, Malaysia. *Environmental Earth Sciences*, 73: 4419-4428.

Saha, D. and Alam, F. (2014). Groundwater vulnerability assessment using DRASTIC and Pesticide DRASTIC models in intense agriculture area of the Gangetic plains, India. *Environmental Monitoring Assessment*, 186: 8741-8763.

Saidi, S., Bouri, S. and Dhia, H.B. (2010). Groundwater vulnerability and risk mapping of the Hajeb-jelma aquifer (Central Tunisia) using a GIS-based DRASTIC model. *Environmental Earth Sciences*, 59: 1579-1588.

Saimy, I.S. and Raji, F. (2015). Applications and sustainability in groundwater abstraction in Malaysia. *Jurnal Teknologi (Sciences & Engineering),* 73 (5): 39-45.

Sajil Kumar, P.J., Jegathambal, P. and James, E.J. (2014). Chemometric evaluation of nitrate contamination in the groundwater of a hard rock area in Dharapuram, south India. *Applied Water Science*, 4: 397-405.

Salman, A., Al-Qinna, M. and Al-Kuisi, M. (2014). Spatial analysis of soil and shallow groundwater physicochemical parameters in El-Mujib Basin-central Jordan. *Journal of Asian Earth Sciences*, 79: 366-381.

Samantara, M.K., padhi, R.K., Satpathy, K.K., Sowmya, M. and Kumaran, P. (2015). Groundwater nitrate contamination and use of CI/Br ratio for source appointment. *Environmental Monitoring Assessment*, 187: 50.

Samsudin, A.R., Haryono, A., Hamzah, U. and Rafek, A.G. (2008). Salinity mapping of coastal groundwater aquifers using hydrogeochemical and geophysical methods: a case study from north Kelantan, Malaysia. *Environmental Geology*. 55: 1737-1743.

Samsudin, A.R., Haryono, Hamzah, U. and Rafek, A.G. (1997). Salinity study of coastal groundwater aquifers in north Kelantan, Malaysia. *Geological Society of Malaysia*, Bulletin 41, December 1997; pp.159-165.

Sankararamakrishnan, N., Sharma, A.K. and Lyengar, L. (2008). Contamination of nitrate and fluoride in groundwater along the Ganges Alluvial Plain of Kanpur district, Uttar Pradesh, India. *Environmental Monitoring and Assessment*, 146: 375-382.

Schaider, L.A., Ackerman, J.M. and Rudel, R.A. (2016). Septic systems as sources of organic wastewater compounds in domestic drinking water wells in a shallow sand and gravel aquifer. *Science of the Total Environment*, 547: 470-481.

Selvam, S., Manimaran, G., Sivasubramanian, P., Balasubramanian, N. and Seshunarayana, T. (2014). GIS-based evaluation of water quality index of groundwater resources around Tuticorin coastal city, south India. *Environmental Earth Science*, 71: 2847-2867.

Shah, K. and Joshi, G.S. (2015). Evaluation of water quality index for River Sabarmati, Gujarat, India. *Applied Water Sciences*. Doi:10.1007/s13201-015-0318-7.

Shamsuddin, A.S., Syed Ismail, S.N., Zainal Abidin, E., Yu Bin, H., Juahir, H. (2016). Contamination of nitrate in groundwater and evaluation of health risk in Bachok, Kelantan: a cross sectional study. *American Journal of Applied Sciences*, 13 (1): 80-90.

Shamsuddin, M.K.N., Suratman, S., Ramli, M.F., Sulaiman, W.N.A. and Sefie, A. (2015). Hydrochemical assessment of surfacewater and groundwater quality at bank infiltration site. *IOP Conference Series: Materials Science and Engineering*, 136 012073.

Shekhar, S., Pandey, A.C. and Tirkey, A.S. (2015). A GIS-based DRASTIC model for assessing groundwater vulnerability in hard rock granitic aquifer. *Arabian Journal of Geosciences*, 8: 1385-1401.

Shirazi, S.M., Imran, H.M., Akib, S., Yusop, Z. and Harun, Z.B. (2013). Groundwater vulnerability assessment in the Melaka State of Malaysia using DRASTIC and GIS techniques. *Environmental Earth Sciences*, 70: 2293-2304.

Shrestha, S., Semkuyu, D.J. and Pandey, V.P. (2016). Assessment of groundwater vulnerability and risk to pollution in Kathmandu Valley, Nepal. *Science of the Total Environment*, 556: 23-35.

Singh, C.K., Shashtri, S. and Mukherjee, S. (2011). Integrating multivariate statistical analysus with GIS for geochemical assessment of groundwater quality in Shiwaliks of Punjab, India. *Environmental Earth Science*, 62: 1387-1405.

Sinha, M.K., Verma, M.K., Ahmad, I., Baier, K., Jha, R. and Azzam, R. (2016). Assessment of groundwater vulnerability using modified DRASTIC model in Kharun Basin, Chhattisgarh, India. *Arabian Journal of Geosciences*, 9: 98.

Srivastava, P., Gupta, M. and Mukherjee, S. (2012). Mapping spatial distribution of pollutants in groundwater of a tropical area of India using remote sensing and GIS. *Applied Geomatics*, 4: 21-32.

Stigter, T.Y., Ribeiro, L. and Carvalho Dill, A.M.M. (2008). Building factorial regression models to explain and predict nitrate concentrations in groundwater under agricultural land. *Journal of Hydrology*, 357: 42-56.

Stigter, T.Y., Ribeiro, L. and Caryalho Dill, A.M.M. (2006). Evaluation of an intrinsic and specific vulnerability assessment method in comparison with groundwater salinisation and nitrate contamination levels in two agricultural regions in the south of Portugal. *Hydrogeology Journal*, 14: 79-99.

Su, Z., Wang, H. and Zhang, Y. (2013). Health risk assessment of nitrate contamination in groundwater: a case study of an agricultural area in Northeast China. *Water Resources Management*, 27: 3025-3034.

Sultana, J., Farooqi, A. and Ali, U. (2014). Arsenic concentration variability, health risk assessment, ans source identification using multivariate analysis in selected villages of public water water system, Lahore, Pakistan. *Environmental Monitoring Assessment*, 186: 1241-1251.

Suthar, S. (2011). Contaminated drinking water and rural health perspective in Rajasthan, India: an overview of recent case studies. *Environmental Monitoring Assessment*, 173: 837-849.

Suthar, S., Bishnoi, P., Singh, S., Mutiyar, P.K., Nema, A.K. and Patil, N.S. (2009). Nitrate contamination in groundwater of some rural areas of Rajasthan, India. *Journal of Hazardous Materials*, 171: 189-199.

Swartijes, F.A. and Grima, J. (2011). Groundwater-related risk assessment. *Dealing with Contaminated Sites*, pp.749-785. Doi: 10.1007/978-90-481-9757-6_17.

Szumilas, M. (2010). Explaining odds ratios. *Journal of the Canadian Academy of Child and Adolescent Psychiatry*, 19 (3): 227-229.

Tedd, K.M., Coxon, C.E., Misstear, B.D.R., Daly, D., Craig, M., Mannix, A. and Hunter Williams, N.H. (2014). An integrated pressure and pathway approach to the spatial analysis of groundwater nitrate: a case study from the southeast of Ireland. *Science of the Total Environment*, 476-477: 460-476.

Tilahun, K. and Merkel, B.J. (2010). Assessment of groundwater vulnerability to pollution in Dire Dawa, Ethiopia using DRASTIC. *Environmental Earth Sciences*, 59: 1485-1496.

Tiwari, A.K., Singh, P.K., Singh, A.K. and Maio, M.D. (2016). Estimation of heavy metal contamination in groundwater and development of heavy metal pollution index by using GIS technique. *Bulletin of Environmental Contamination and Toxicology*, 96: 508-515.

U.S. Environmental Protection Agency. (2016). Human Health Risk Assessment.Retrieved from http://www.epa.gov/ risk/health-risk.htm.

U.S. EPA Region 6 (2005) Human Health Risk Assessment Protocol.Retrieved from http://www.epa.gov/osw/hazard/tsd/td/combust/finalmact/ssra/05hhrap7.pdf.

Usman, U.N., Toriman, M.E., Juahir, H., Abdullahi, M.G., Rabiu, A.A. and Isiyaka, H. (2014). Assessment of groundwater quality using multivariate statistical techniques in Terengganu. *Science and Technology*, 4 (3): 42-49.

Varol, S. and Davraz, A. (2015). Evaluation of the groundwater quality with WQI (Water Quality Index) and multivariate analysis: a case study of the Tefenni plain (Burdur/Turkey). *Environmental Earth Sciences*, 73: 1725-1744.

Vasanthavigar, M., Srinivasamoorthy, K., Vijayaragan, K., Rajiv Ganthi, R., Chidambaram, S., Anandhan, P., Manivannan, R. and Vasudevan, S. (2010). Application of water quality index for groundwater quality assessment: Thirumanimuttar sub-basin, Tamilnadu, India. *Environmental Monitoring Assessment*, 171: 595-609.

Victorine Neh, A., Ako, A.A., Ayuk II, A.R. and Hosono, T. (2015). DRASTIC-GIS model for assessing vulnerability to pollution of the phreatic aquiferous formations in Douala-Cameroon. *Journal of African Earth Sciences*, 102: 180-190.

Volkmer, B.G., Ernst, B., Simon, J., Kuefer, R., Bartsch Jr, G., Bach, D. and Gschwend, J.E. (2005). Influence of nitrate levels in drinking water on urological malignancies: a community-based cohort study. *BJU International*, 95: 972-976.

Wada, Y., van Beek, L.P.H., van Kemper, C.M., Reckman, J.W.T., Vasak, S. and Bierkens, M.F.P. (2010). Global depletion of groundwater resources. *Geophysical Research Letters*, 37(20). Doi: 10.1029/2010GL044571.

Wang, L., Stuart, M.E., Lewis, M.A., Ward, R.S., Skirvin, D., Naden, P.S., Collins, A.L. and Ascott, M.J. (2016). The changing trend in nitrate concentrations in major aquifers due to historical nitrate loading from agricultural land across England and Wales from 1925 to 2150. *Science of the Total Environment*, 542: 694-705.

Ward, M.H. (2009). Too much of a good thing? Nitrate from nitrogen fertilizers and cancer. *Reviews on Environmental Health*, 24 (4): 357-363.

Ward, M.H., deKok, T.M., Levallois, P., Brender, J., Gulis, G., Nolan, B.T. and VanDerslice, J. (2005). Workgroup report: Drinking-water nitrate and health-recent findings and research needs. *Environmental Health Perspective*, 113 (11): 1607-1614.

Ward, M.H., Heineman, E.F., Markin, R.S., and Weisenburger, D.D. (2008). Adenocarcinoma of the stomach and esophagus and drinking water and dietary sources of nitrate and nitrite. *International Journal of Occupational and Environmental Health*, 14 (3): 193-197.

Ward, M.H., Kilfoy, B.A., Weyer, P.J., Anderson, K.E., Folsom, A.R. and Cerhan, J.R. (2010). Nitrate intake and the risk of thyroid cancer and thyroid disease. *Epidemilogy*, 21 (3): 389-395.

Ward, M.H., Rusiecki, J.A., Lynch, C.F. and Cantor K.P. (2007). Nitrate in public water supplies and the risk of renal cell carcinoma. *Cancer Causes Control*, 18: 1141-1151.

Wen, X., Wu, J., Si, J. (2009). A GIS-based DRASTIC model for assessing shallow groundwater vulnerability in the Zhangye Basin, northwestern China. *Environmental Geology*, 57: 1435-1442.

Wheeler, D.C., Nolan, B.T., Flory, A.R., DellaValle, C.T. and Ward, M.H. (2015). Modeling groundwater nitrate concentrations in private wells in Iowa. *Science of the Total Environment*, 536: 481-488.

WHO (2011).Guidelines for Drinking-water Quality. 4th edn. Geneva. World Health Organization.

Wick, K., Heumesser, C. and Schmid, E. (2012). Groundwater nitrate contamination: Factors and indicators. *Journal of Environmental Management*, 111: 178-186.

Wongsanit, J., Teartisup, P., Kerdsueb, P., Tharnpoophasiam, P. and Worakhunpiset, S. (2015). Contamination of nitrate in groundwater and its potential human health: a case study of lower Mae Klong river basin, Thailand. *Environmental Science Pollution Research*, 22: 11504-11512.

Wongsasuluk, P., Chotpantarat, S., Siriwong, W. and Robson, M. (2014). Heavy metal contamination and human health risk assessment in drinking water from shallow groundwater wells in an agricultural area in Ubon Ratchathani province, Thailand. *Environmental Geochemistry and Health*, 36: 169-182.

Wu, J. and Sun, Z. (2016). Evaluation of shallow groundwater contamination and associated human health risk in an alluvial plain impacted by agricultural and industrial activities, Mid-west China. *Expsoure and Health*, 8: 311-329.

Xie, Y., Chen, T-b., Lie, M., Yang, J., Guo, Q-j., Song, B. and Zgou, X-y. (2011). Spatial distribution of heavy metal pollution estimated by different interpolation methods: accuracy and uncertainty analysis. *Chemosphere*, 82: 468-476.

Xun, Z., Hua, Z., Liang, Z., Ye, S., Xia, Y., Rui, L. and Li, Z. (2007). Some factors affecting TDS and pH values in groundwater of the Beihai coastal area in southern Giangxi, China. *Environmental Geology*, 53: 317-323.

Yan, S-f., Yu, S-e., Wu, Y-b., Pan, D-f., She, D-l.and Ji, J. (2015). Seasonal variation in groundwater level and salinity in coastal plain of Eastern China influenced by climate. *Journal of Chemistry*.Vol. 2015, Article ID 905190, 8 pages, Doi:10.1155/2015/905190.

Yang, H. and Cheng, H. (2007). Controlling nitrite level in drinking water by chlorination and chloramination. *Separation and Purification Technology*, 56: 392-396.

Yidana, S.M., Banoeng-Yakubo, B. and Akabzaa, T.M. (2010). Analysis of groundwater quality using multivariate and spatial analyses in the Keta basin, Ghana. *Journal of African Earth Sciences*, 58: 220-234.

Yin, L., Zhang, E., Wang, X., Wenninger, J., Dong, J., Guo, L. and Huang, J. (2013). A GIS-based DRASTIC model for assessing groundwater vulnerability in the Ordos Plateau, China. *Environmental Earth Sciences*, 69: 171-185.

Yu, Q., Cao, Q. and Connell, D.W. (2012). An overall risk probability-based method for quantification of synergistic and antagonistic effects in health risk assessment for mixtures: theoretical concept. *Environmental Sciences and Pollution Research*, 19: 2627-2633.

Zainal Abidin, E., Semple, S., Rasdi, I., Syed Ismail, S.N. and Ayres, J.G. (2014). The relationship between air pollution and asthma in Malaysian school children. *Air Quality Atmosphere and Health*, 7: 421-432.

Zeegers, M.P., Selen, R.F.M., Kleinjans, J.C.S., Goldbohm, R.A. and van der Brand, P.A. (2006). Nitrate intake does not influence bladder cancer risk: the Netherlands cohort study. *Environmental Health Perspectives*, 114 (10): 1527-1531.

Zghibi, A., Merzougui, A., Chenini, I., Ergaieg, K., Zouhri, L. and Tarhouni, J. (2016). Groundwater vulnerability analysis of Tunisian coastal aquifer: an application of DRASTIC index method in GIS environment. *Groundwater for Sustainable Development*, 2; 169-181.

Zhai, X., Xia, J. and Zhang, Y. (2014). Water quality variation in the highly distributed Huai River Basin, China from 1994 to 2005 by multi-statistical analyses. *Science of the Total Environment*, 496: 594-606.

Zhai, Y., Zhao, X., Teng, Y., Li, X., Zhang, J., Wu, J. and Zuo, R. (2017). Groundwater nitrate pollution and human health risk assessment by using HHRA model in an agricultural area, NE China. *Ecotoxicology and Environmental Safety*, 137: 130-142.

Zhang, Q., Sun, J., Liu, J., Huang, G., Lu, C., and Zhang, X. (2015). Driving mechanism and sources of groundwater nitrate contamination in the rapidly urbanized region of south China. *Journal of Contaminant Hydrology*, 182: 221-230.

Zhang, X., Ren, L. and Kong, X. (2016). Estimating spatiotemporal variability and sustainability of shallow groundwater in a well-irrigated plain of the Haihe River basin using SWAT model. *Journal of Hydrology*, 541: 1221-1240.

Zhang, Y., Li, F., Zhang, Q., Li, J. and Liu, Q. (2014). Tracing nitrate pollution sources and transformation in surface- and ground-waters using environmental isotopes. *Science of the Total Environment*, 490: 213-222.

Zhou, Y., Wei, A., Li, J., Yan, L. and Li, J. (2016). Groundwater quality evaluation and health risk assessment in the Yinchuan Region, Northwest China. *Exposure and Health*, 8: 443-456.

Zirkle, K.W., Nolan, B.T., Jones, R.R., Weyer, P.J., Ward, M.H. and Wheeler, D.C. (2016). Assessing the relationship between groundwater nitrate and animal feeding operations in Iowa (USA). *Science of the Total Environment*, 566-567: 1062-1068